National Renewable Energy Laboratory

Enzyme Sugar Platform (ESP) Project

Next Steps

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FY03 Review Meeting

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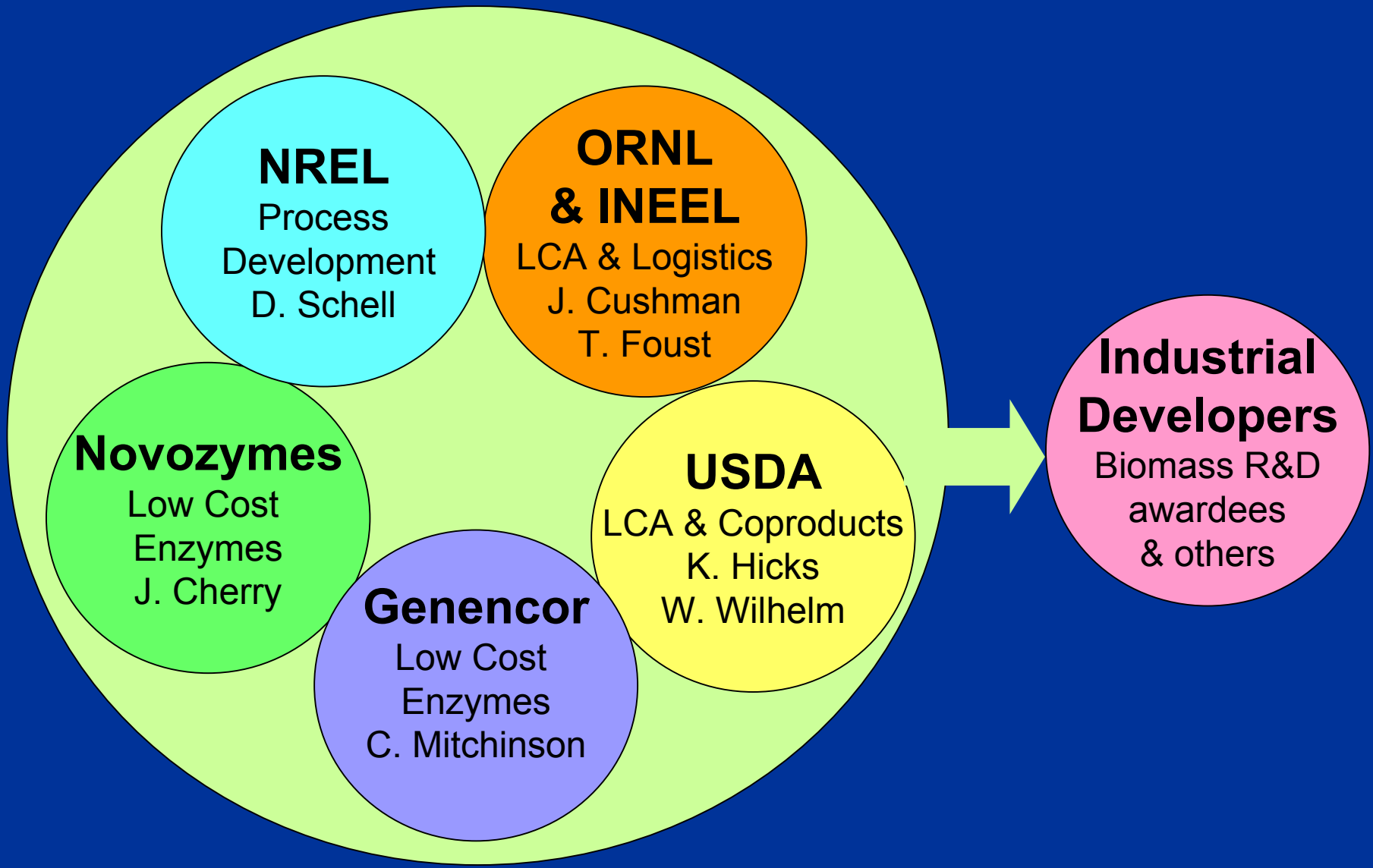
High-Level Project Mission

Facilitate commercialization of enzyme-based cellulose hydrolysis “Sugar Platform” technology by advancing enabling tools and knowledge.

Critical Success Factors

1. The integrated process must perform reliably at levels commensurate with attractive economics
    - Focus of ESP core research activities as well as work in technoeconomic analysis and analytical method development
2. Sufficient quantities of corn stover (or other feedstock) must be sustainably available at an acceptable cost
    - Focus of life cycle analysis and infrastructure studies by NREL, ORNL, INNEL, USDA and others
3. Cost-effective cellulase enzymes must be available
    - Being developed by enzyme manufacturers

Main Project Participants

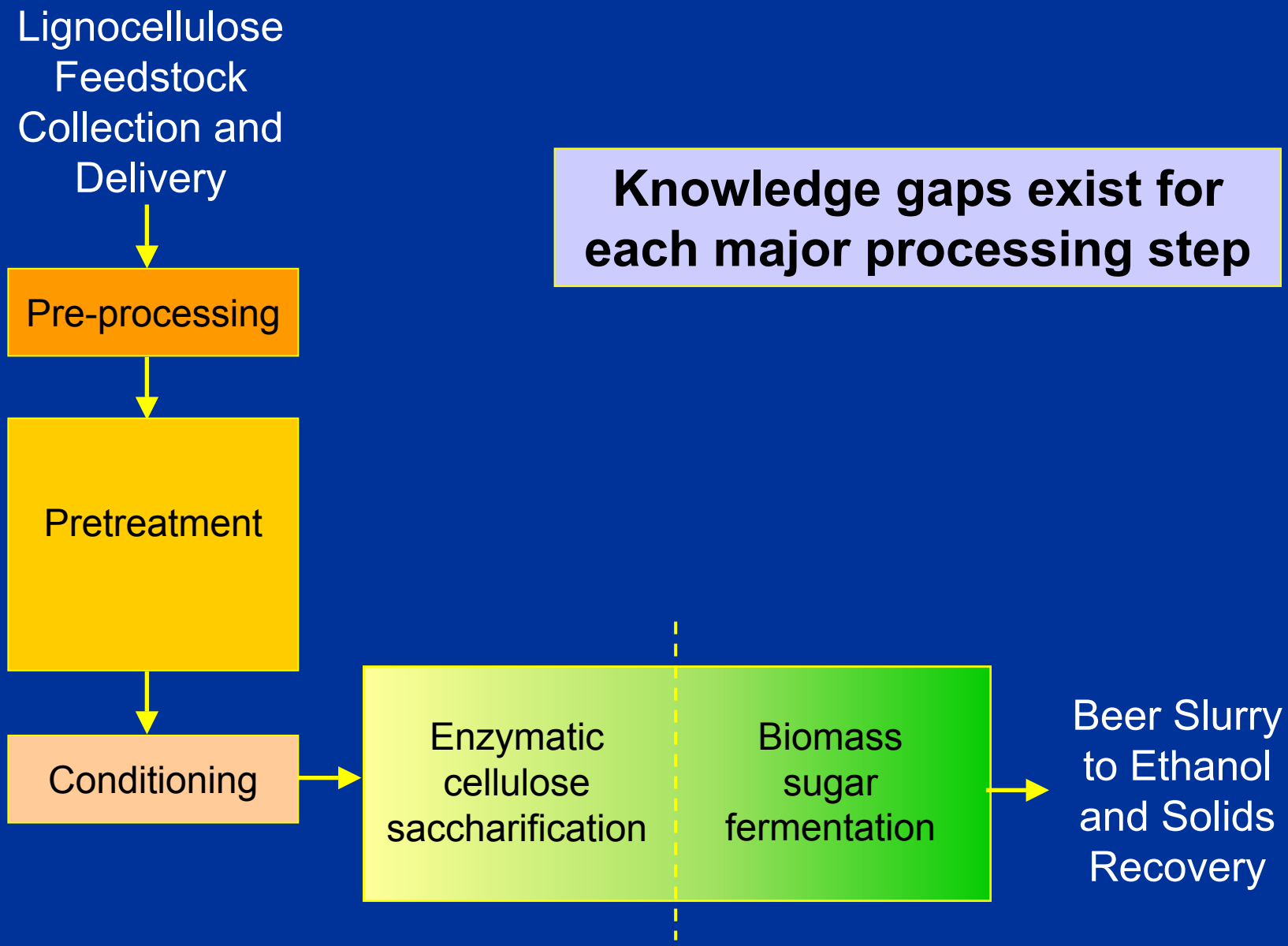


Adding Value

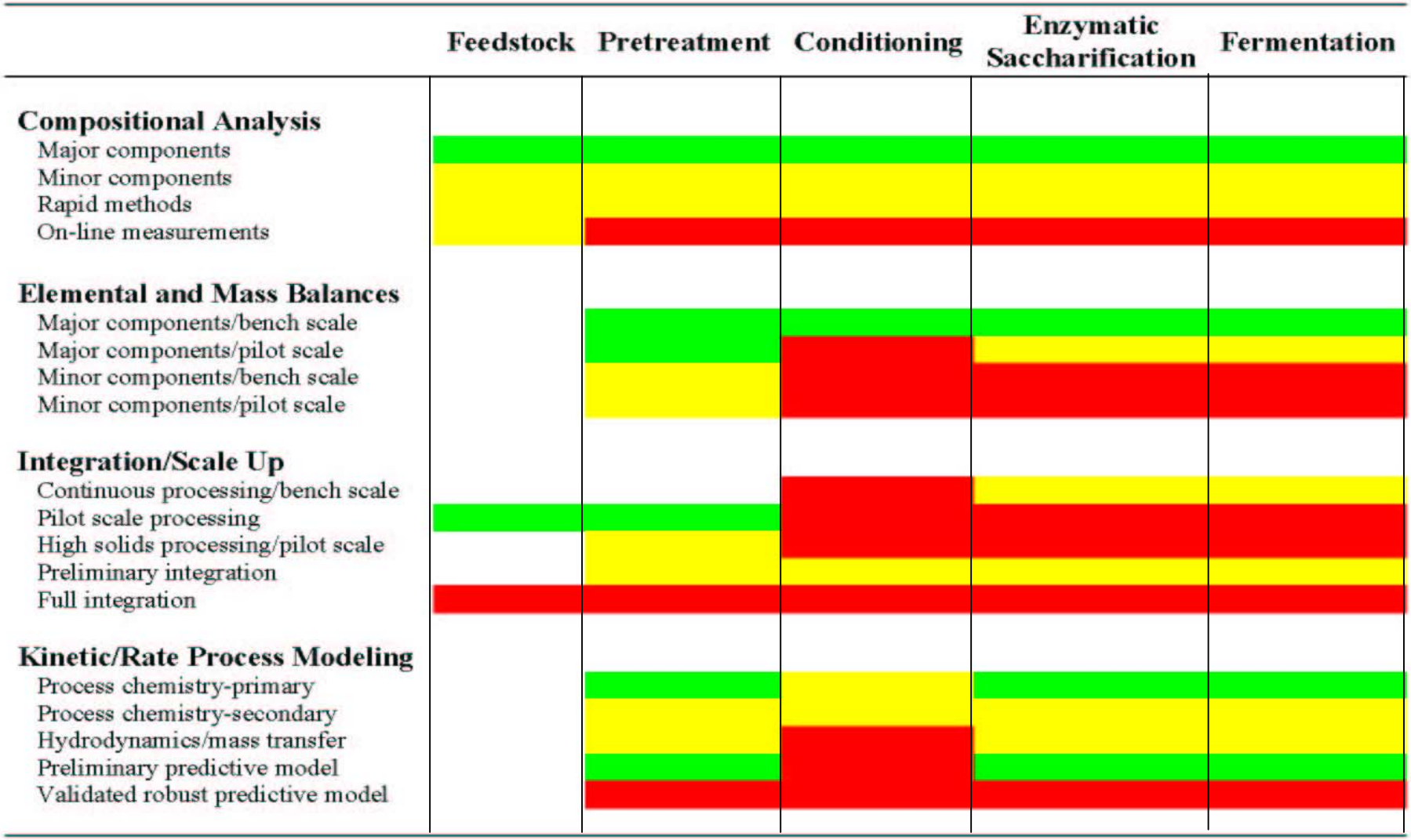
- Enable external sugar platform RD&D
  - Produce process samples for stakeholder and third party evaluation
  - Provide high quality performance data to support process engineering and economic analyses
- Advance knowledge and enabling tools
  - Validate methodologies for high quality carbon closures
  - Understand key process interactions involved in core saccharification steps
  - Identify knowledge gaps

➢ Reduce technology uncertainty and performance risk

Major Steps in an Enzymatic Process



Process Development Knowledge Gap Analysis



ESP Core Research Activities

- Corn Stover Variability
- Pretreatment
- Cellulose Hydrolysis/Integrated Processing

Progress in Corn Stover Variability Analysis

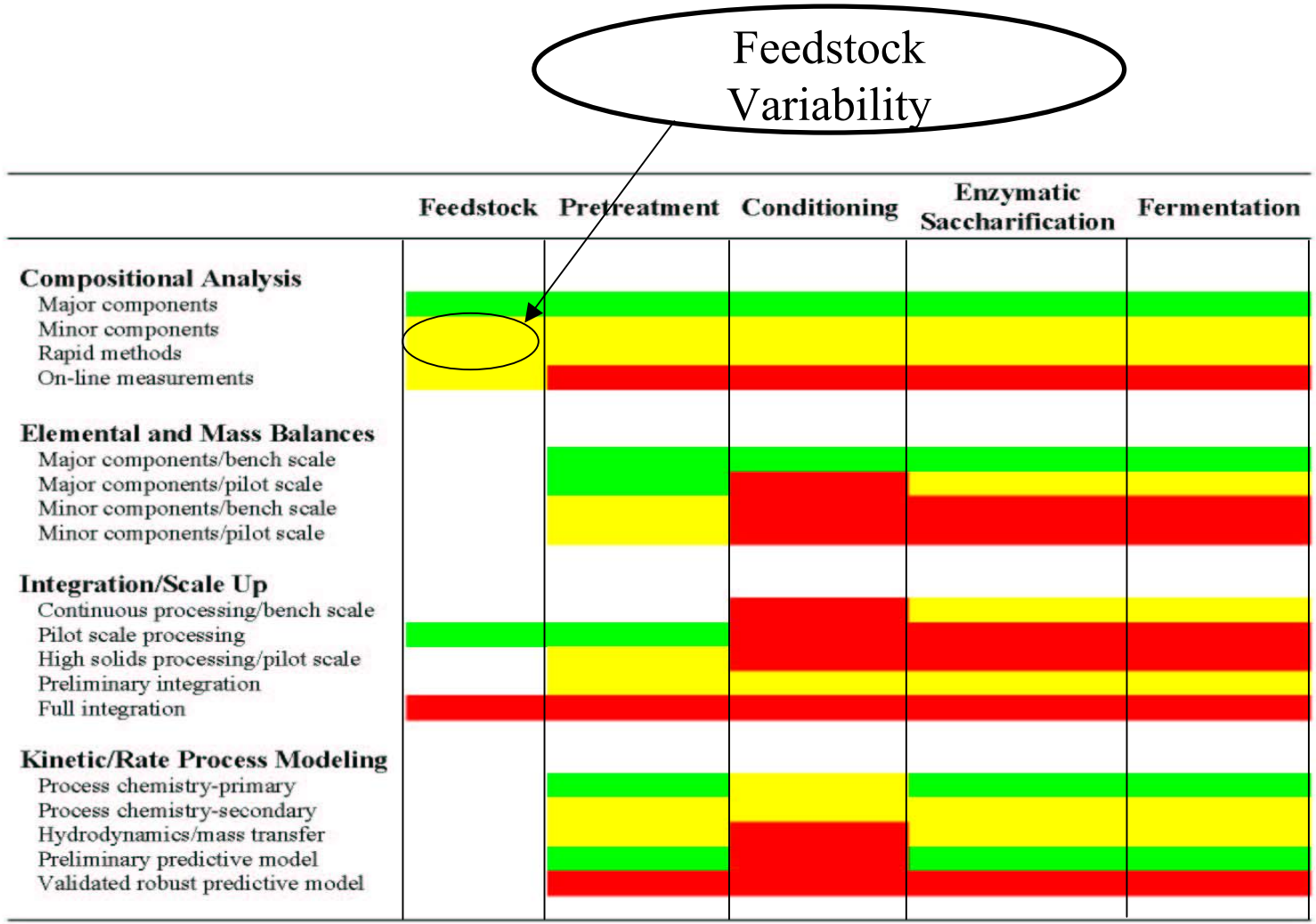
Addressing/Overcoming Barriers

- Feedstock variability
  - Determined that corn stover compositional variability spanned a wide range of total structural carbohydrates, ~23%
- Cost and risk
  - The impact of observed compositional variation on MESP is up to $0.30/gal

Recommendations
Corn Stover Variability

- Near-term
  - Continue to monitor diverse stover samples
    - Partner with USDA National Plant Germplasm System
  - Cultivate relationships with seed companies and breeders
- Long-term
  - Determine major genetic and environmental factors influencing stover quality
    - Partner with USDA
  - Investigate new tools to distinguish and quantify differences in cell wall architecture

Process Development Knowledge Gap Analysis



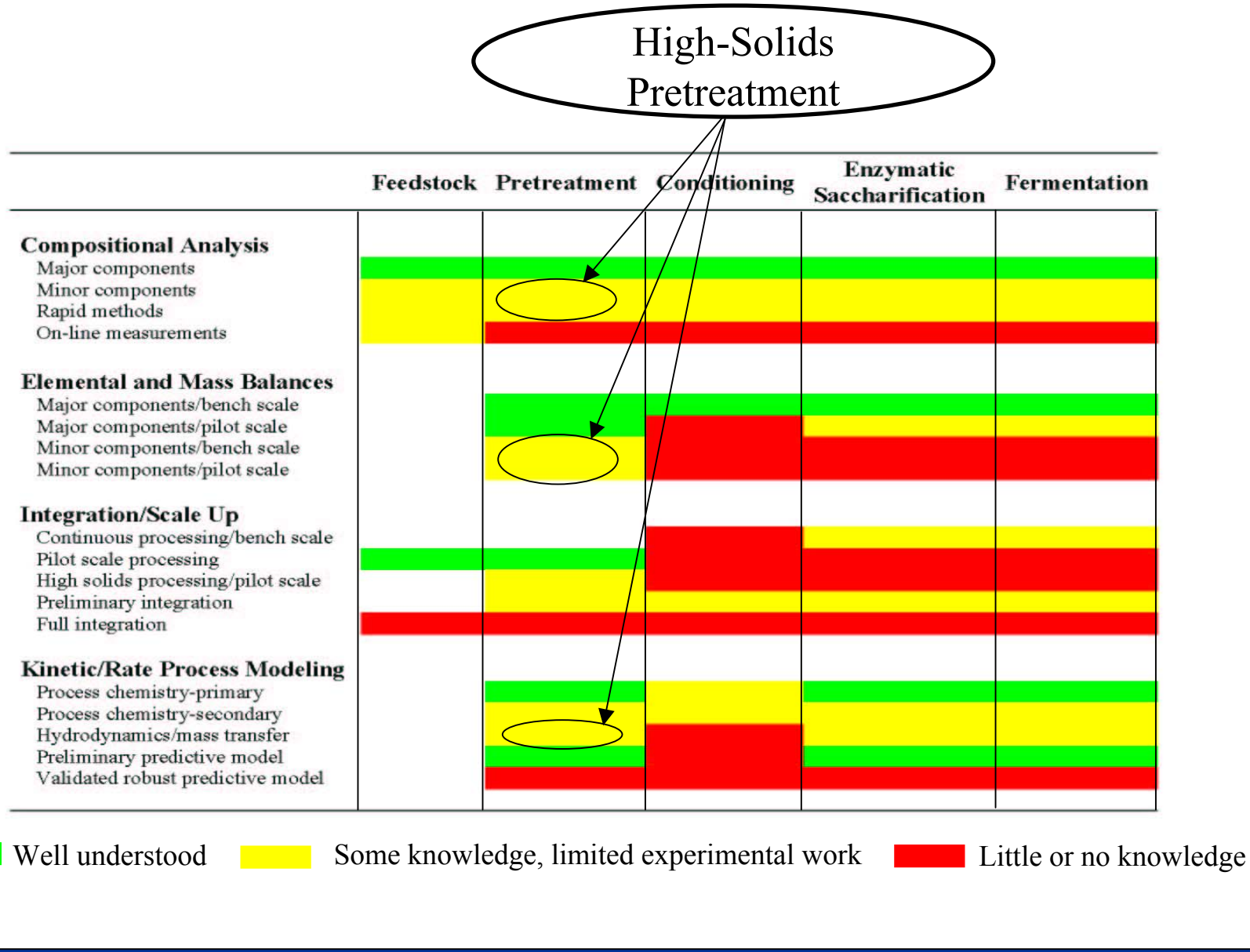
Pretreatment Progress
Addressing/Overcoming Barriers

- High solids processing
  - Ability of pilot-scale system to operate at high solids improved from 20% to 35% solids
  - Limited data generated at 25%-35% solids, but in position to explore a wide range of solids concentration
- Role of biomass structure and composition
  - Identified that hemicellulosic sugar yields and enzymatic cellulose digestibilities are influenced by corn stover composition

Recommendations
Pretreatment

- Near-term
  - Supply materials to stakeholders for co-product studies
  - Characterize high-solids pretreatment
    - Mass transfer limitations, carbon/mass balances, factors affecting enzymatic hydrolysis
- Long-term
  - Continue to assess effect of corn stover compositional variability on pretreatment performance
    - Effect of fine structure

Process Development Knowledge Gap Analysis



Cellulose Hydrolysis/Integrated Processing Progress

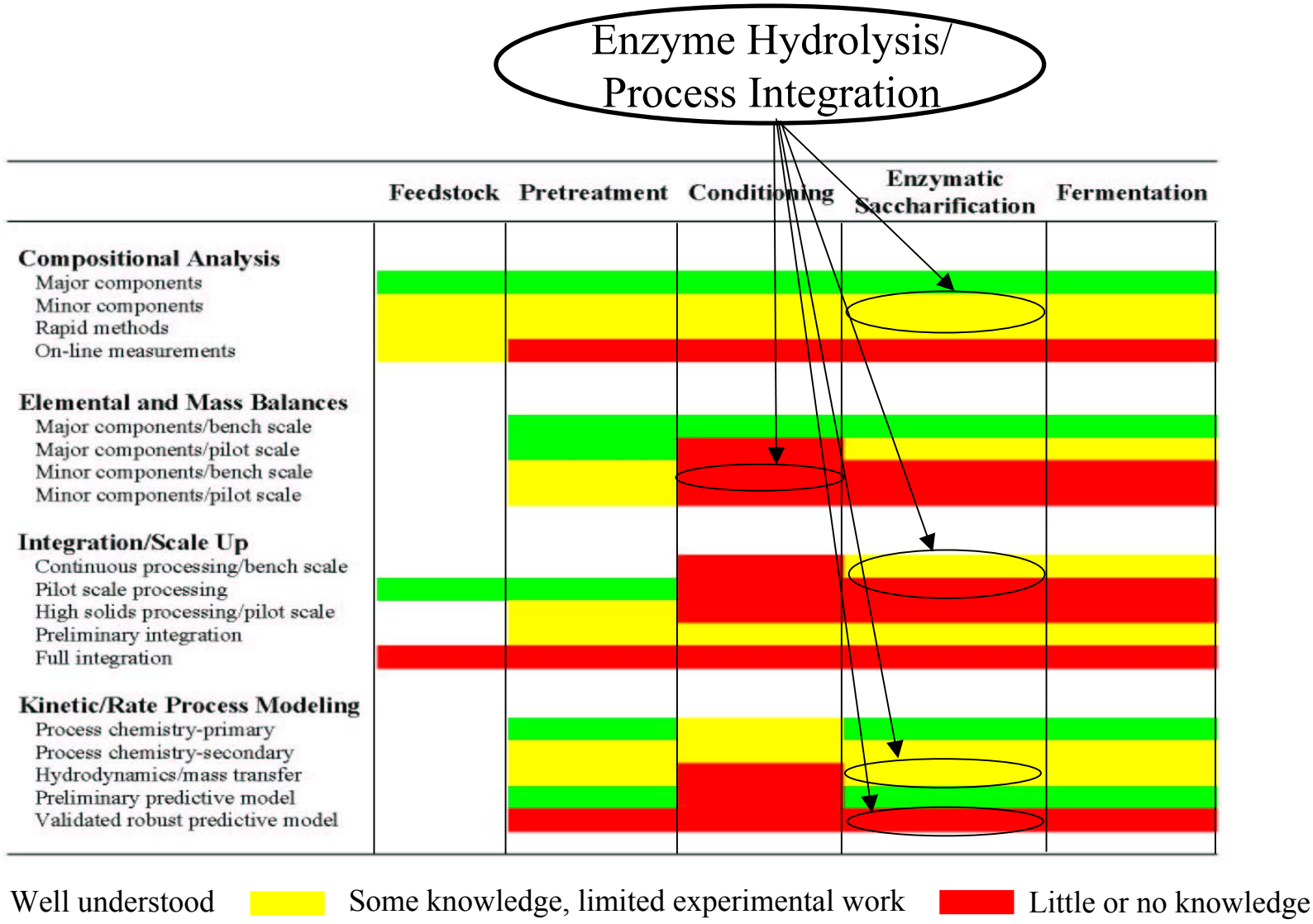
Addressing/Overcoming Barriers

- Understanding key process interactions
  - Saccharification performance not influenced by conditioning protocol (liming .vs. overliming)
  - Good cellulose solubilization (80%-90%) achieved in shake flask with relatively high background hydrolysate sugar levels of ~ 15-20 g/L glucose and ~50-60 g/L xylose at modest solids loading
- Kinetic models
  - Developed baseline saccharification model

Key Recommendations
Enzymatic Hydrolysis/Process Integration

- Near-term
  - Evaluate new lower-cost 2nd generation enzymes
    - Integrated processing
    - Determine parameters for kinetic model
  - Mass balance hydrolysate conditioning step
    - Fate of Ca and S
- Long-term
  - Process integration
    - Obtain data on separation processes (esp. S/L)
    - Investigate factors promoting cellulose saccharification
    - Apply new analytical tools to improve carbon/mass balance closure
  - Explore saccharification/fermentation process configurations and reactor designs
  - Improve saccharification kinetic model and validate for batch hydrolysis

Process Development Knowledge Gap Analysis



ESP Core Research Proposed Timeline

Corn stover variability

- Near-term
- Long-term

Pretreatment

- Supply material
- High-solids work
- Long-term

Enzyme hydrolysis/process integration

- Evaluate new enzymes
- Conditioning mass bal.
- Process integration
- Long-term

Related Sugar Platform Activities

- Process Modeling and Economics
- Life Cycle Analysis

Sugar Platform Objectives
Process Modeling and Economics

- Near-term: Improve rigor of process models
  - Emissions
  - Biomass handling
  - Material/component flows and balances
  - Separation equipment performance
- Long-term:
  - Track technology progress using improved data
    - Update risk analysis based on experimental error/uncertainty
    - Improve understanding of feedstock cost structure
  - Increase model sophistication
    - Incorporate kinetic models into existing simulations
    - Develop linear programming models for biorefineries

Sugar Platform Objectives

Life Cycle Analysis

- Define, identify and model realistic and sustainable crop rotations
- Address water quality concerns
- Address broader national potential of corn stover and wheat straw as large volume sustainable resources

Proposed Project Resources

Staff years

Activity	FY02 (actual)	FY03 (ESP plan)	FY04 (proposed, ESP and related sugar platform)
Proj. management/communication	1.0	0.7	0.5
Process modeling and economics	2.2	1.0	1.0
Sample compositional analysis	1.5	0.5	2.0
Corn stover variability	1.4	0.7	0.5
Pretreatment	2.2	1.6	1.5
Fermentation strain evaluation	1.2	0.0	0.0
Enzyme hydrolysis/process integration	1.2	1.8	2.5
Total	10.7	6.3	8.0
Other			
Life Cycle Analysis	0.25	0.25	2.0
Enzyme Testing/Evaluation	1.5	2.2	1.0

Thank You

- Enzyme Sugar Platform Reviewers
  - Charles Abbas, ADM
  - Dale Monceaux, Katzen International
  - Bob Sylvester, DuPont
  - Bob Wooley, Cargill-Dow
- ESP Project Team Members
- Project Participants from INNEL, ORNL, USDA, Genencor, and Novozyme
- Review Meeting Participants

Questions?

Comments?

Suggestions?